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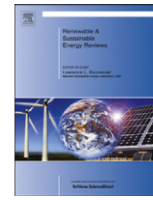

Investigation of wind characteristics and wind energy potential in Osmaniye, Turkey

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ABSTRACT

Turkey is a country that is dependent on foreign energy; the majority of Turkey's energy needs are supplied through imports. Renewable energy sources are becoming important in Turkey due to both the country's energy dependency and the disadvantages of using fossil fuels. Turkey has begun to use renewable energy sources, especially wind energy, which has a high potential in the country. Moreover, investigations of and investments in wind power have increased recently.

This study investigates the wind energy potential that is a result of the distribution of wind speeds in Osmaniye,which is located east of the Mediterranean Sea in Turkey. The Weibull and Rayleigh distribution methods, which are generally used for this type of wind energy study, are employed. The approximate wind energy potential was obtained and indicates whether the region is suitable for related investments. Wind data, consisting of wind speed, direction and flow time at a height of 10 m, were collected by the Turkish State Meteorological Service for a period of 44 months, from January 2008 to August 2011. To determine the Weibull parameters, a graphical method is used; hence, the mean annual value of the shape parameter (k) is between 1.00 and 1.04, while the annual value of the scale parameter (c) is between 1.59 and 1.66 m/s. The average wind speed and wind potential energy are 2.23 m/s and 24.587 W/m^2, respectively.

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Contents

1. Introduction

Energy consumption in Turkey is increasing quickly due to the development of industry and an increasing population. Although Turkey has a wide range of energy resources, including coal, natural gas, and petroleum, these resources are limited. Therefore, Turkey has begun to investigate alternative energy resources. The investigation of wind energy has been rapid in Turkey because of its high potential.

According to the "Turkish Wind Map", which was prepared by the General Directorate of Electrical Power Resources (EIE), the wind speeds at a height of 50 m outside residential areas, such as those at Marmara, along the West Black Sea, and on the eastern Mediterranean coast, and the speeds inland of these regions are

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6.0–7.0 and 4.5–5.0 m/s, respectively. The northwest Aegean coastal areas also have wind speeds of 7.0–8.5 m/s, with speeds of 6.5–7.0 m/s inland. In addition, the meteorological data from space studies in the USA have demonstrated that Turkey has a high wind capacity [1,2]. Turkey's annual theoretically available potential for wind power is calculated to be more than 80 GW, of which approximately 10 GW is also economically feasible [3].

The utilization of wind energy in Turkey began in 1998, when the first wind-based power plant, with a total capacity of 1.5 MW, was installed in the Izmir-Cesme-Germiyan region [4]. The investment in wind energy in Turkey has increased over last three years. In 2008, production plants with a total capacity of 287.0 MW were established in Istanbul-Gaziosmanpasa and Catalca, Izmir-Aliaga, Balikesir-Bandirma, Samli, Hatay-Samandag, Manisa-Sayalar, Mugla-Datça and Canakkale. By the end of 2009, production plants with a total capacity of 403.0 MW were established in Osmaniye-Bahce, Izmir-Cesme, Hatay-Samandag and Manisa-Soma, bringing the total capacity to 835.95 MW [5]. By the year 2010, Turkey's installed potential wind power capacity reached 1522.2 MW. The report also stated that the total installed wind power capacity would be 2166.65 MW by the end of 2011 in Turkey [6]. The historical development of wind energy in Turkey is illustrated in Fig. 1. Currently, the largest single installed wind project in Turkey is the Gokcedag Wind Farm in Osmaniye-Bahce. There, Rotor Elektrik, a member of Zorlu Energy Group, installed 54 General Electric 2.5xl (2.5 MW) wind turbines, for a total of 135 MW [7].

The wind energy potential for a selected site is determined by developing detailed knowledge of the wind characteristics, such as speed, direction, continuity and availability [8]. Many recent studies have investigated wind characteristics based on different mathematical methods, such as the Weibull and Rayleigh methods. Some authors have used the Wind Atlas Analysis and Application Program (WASP) to evaluate the wind energy potential for a region. Analyses of wind characteristics have been conducted at different temporal scales, such as yearly, seasonal and monthly, based on the time scale of the wind data from the region.

Many studies of wind characteristics and wind power potential have been counducted in many countries worldwide. Youm et al. [9] presented the wind power potential along the northern coast of Senegal by collecting wind data over a period of two years at five different locations in the region. Keyhani et al. [10] conducted a study using statistical data from eleven years of wind speed measurements from Tehran, the capital of Iran, to determine the wind energy potential. Tchinda and Kaptoum [11] evaluated the wind power potential for Adamaoua and the North Cameroon Provinces. Lima and Filho [12] investigated the wind

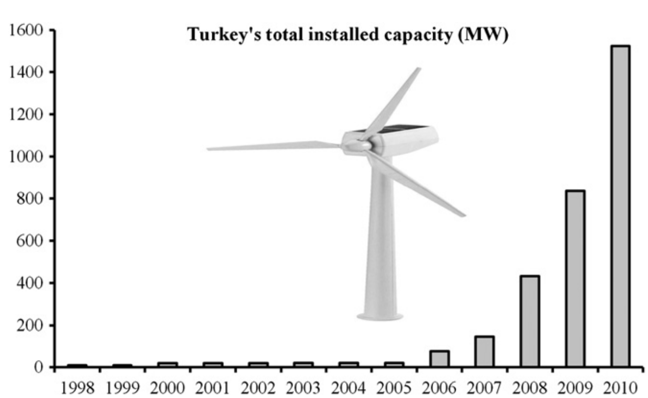

Fig. 1. Growth of wind energy in Turkey.

power potential for the city of Triunfo, which is located in the state of Pernambuco in northeast Brazil. Albuhairi [13] presented the results of an analysis of hourly wind speed data for one year at Taiz City, which is located in southwestern Yemen. The wind energy potential for Taiz City was analyzed using the Weibull and Rayleigh models, and the authors concluded that the location should be explored for wind energy. Mostafaeipour et al. [14] investigated the status and wind power potential of the city of Shahrbabak in the Keman Province. The mean wind speed data from a dataset with three-hour intervals between observations from 1997 to 2005 were analyzed to determine the potential for wind power generation. The technical and economic feasibility of wind turbine installation was presented in the study. Mirhosseini et al. [15] analyzed wind speed data that were recorded every three hours from 2003–2007 at 10 m, 30 m and 40 m heights in the Semnan Province in Iran. The potential for wind power generation was evaluated for five towns in the province, i.e., Biarjmand, Damghan, Garmsar, Semnan and Shahrood. Dahmouni et al. [16] evaluated the wind energy potential and the electrical capacity generation for Borj-Cedria in Tunisia. The seasonal mean wind speed, wind speed distribution and wind power density were estimated using the wind speed data that were collected at 30, 20 and 10 m heights from 2008 to 2009 at two meteorological stations. Fyrippis et al. [17] investigated the wind power potential of Koronos village, in the northeastern region of Naxos Island, Greece. According to the results from that study, the selected site falls under Class 7 of the international system of wind classification because the mean annual wind speed in the area was 7.4 m/s and the corresponding annual mean power density was estimated to be 420 W/m^2. Li and Li [18] analyzed the wind potential and characteristics of the Waterloo region, Canada, at annual, seasonal, monthly and diurnal time scales for five years (1999–2003). Kitaneh et al. [19] evaluated the daily mean wind speed data for 4 locations in Palestine over a period of 5 years. Mohammadi et al. [20] investigated the wind energy potential of the City of Zarrineh in Iran and assessed whether the standard deviation or the power density method was the best method for calculating wind power. Mostafaeipour et al. [21] analyzed hourly wind speed data for 2007–2010 at 10 m, 30 m and 40 m heights in the Binalood region in Iran to determine the potential for wind power generation and found that Binalood has a high wind energy potential for a grid connection system. Alamdari et al. [22] investigated the most important characteristics of wind energy for sixty-eight different locations in Iran using a ten-minute time interval of wind speed data at 10 m, 30 m and 40 m heights. Lashin and Shata [23] analyzed wind speed data that were measured at a height of 19 m in coastal Port Said in Egypt. There, the wind speed was greater during spring months than winter months, which is the opposite of the prevailing wind speed parameters in most European countries. Aman et al. [24] estimated the wind energy potential in Karachi, Pakistan, using wind speed data that were obtained from the Pakistan Metrological Department (PMD) for various heights (i.e., 10 m, 30 m, 50 m, 75 m and 100 m) over four years. In this study, the statistical calculations using SPSS (Statistical Package for the Social Sciences) software indicated that the city has an enormous wind potential available. Durisic and Mikulovic [25] analyzed the wind energy resources in the South Banat region. The analyses were conducted using wind parameter measurements from the village of Bavaniste. The data were collected at the heights of 10, 40, 50, and 60 m during 2009 and 2010. The results demonstrated that the region of South Banat has a high wind energy potential and represents a promising region for the development of wind farms. Himri et al. [26] evaluated long-term (obtained over 8 years) wind speed data based on annual, seasonal and diurnal variations at Tindouf, in southwestern Algeria. Mpholo et al. [27] analyzed the wind profile of two sites, i.e., Masitise and Sani, in Lesotho. In this study, the wind speed measurements for Masitise were taken at

both 10 m and 25 m, while at Sani, anemometers were only placed 9 m above ground level.

Many studies focus on Turkey's wind characteristics to locate regions that are highly suitable for wind energy applications. For instance, Ucar and Balo [28] investigated the wind energy potential at twelve locations in the coastal regions of Turkey. The wind characteristics and wind energy potential of the Uludag-Bursa, which is located in the south Marmara region of Turkey, were analyzed using wind speed data that were collected from 2000–2006 [29]. Eskin et al. [30] used wind data that were collected over a period of 3 years at the Ugurlu and Cinaralti stations and over a period of 10 years at Aydincik and the National Weather Station to estimate the wind energy potential of Gokceada Island in the Northern Aegean Sea in Turkey. The wind energy potential of various regions and the exploitation of wind energy were investigated by analyzing wind data that were measured hourly at windy locations in Turkey [31]. The wind data that were used in this study were obtained from the Electrical Power Resources Survey and Development Administration (EIEI) for the year 2004. Onat and Ersoz [32] evaluated the wind climate features of three regions in Turkey (i.e., Samandag-Mediterranean, Amasra-West Black Sea and Guney-Interior Aegean) as well as their energy potential. To determine the wind features in these regions, a five-layer Sugeno-type ANFIS model was developed using MATLAB-Simulink software and the relationships between wind speed and other climate variables were determined. Celik [33] analyzed the wind energy potential for southern Turkey based on a one-year, hourly time series of wind speed data. Sahin and Bilgili [34] investigated wind characteristics of the Belen-Hatay Province, which is located in southern Turkey, for future wind power generation projects. In their study, the mean wind speed and power potential at the site were 7.0 m/s and 378 W/m^2, respectively, at a height of 10 m above ground level. Gokcek et al. [8] provided the wind characteristics and wind energy potential for the Kirklareli Province in the Marmara region by calculating the Weibull and Rayleigh probability density functions for this location. In their study, the Weibull shape parameter, k and the scale parameter, c, were 1.75 and 5.25 m/s, respectively, for the year 2004. The investigated site has a fair wind energy potential, according to the results. Another estimate of the wind energy potential and micrositing process for the campus of the Izmir Technology Institute was made by Ozerdem and Turkeli [35]. The wind data that were used in their study were collected at 10 and 30 m heights for a period of 16 months. A wind energy map for the campus area was also created for this study. Akpinar et al. [36] investigated the wind energy potential using wind speed data from four stations that were located in and near Elazig. In their study, wind data were fitted to the Weibull and Rayleigh probability distribution functions, which were then compared to each other. The annual wind speed and power are 5.66 m/s and 246.27 W/m^2 for Maden, 3.86 m/s and 98.90 W/m^2 for Agin, 3.14 m/s and 41.337 W/m^2 for Elazig, 2.27 m/s and 15.83 W/m^2 for Keban. Maden has a high wind energy potential compared to the other three regions; therefore, this region is ideal for grid-connected applications. However, the annual mean wind power densities in the Agin, Elazig and Keban regions were not high enough for electricity production. In addition, the Keban region may be adequate for non-connected electrical and mechanical applications, such as wind generators, battery charging and water pumping. Kose [37] evaluated the wind energy potential in Kutahya using wind data from a wind observation station on the Dumlupinar University Campus. In this study, the dataset was searched to determine whether electricity can be produced from the wind energy. The average measured wind speed over a period of 20 months was 4.62 m/s at 30 m height and the energy density was 36.62 W/m^2. The authors concluded that the location was unsuitable for producing electricity from wind energy and that the data should be reevaluated over the long term, based on with technological developments and reductions in the cost of turbines. Karsli and Gecit [38] evaluated the wind power potential in Nurdagi-Gaziantep, in southern Turkey (approximately 67 km from Osmaniye) and calculated a mean wind speed of 7.3 m/s at 10 m height above the ground level. They determined that the highest speed of wind at the site is 23.3 m/s and the mean power density is 222 W/m^2. Celik [39] investigated the wind energy potential of the Canakkale and Bozcaada regions using the Weibull and Rayleigh models. An hourly time-series of wind speed data from a height of 10 m was analyzed and the results were evaluated. Ucar and Balo [40] analyzed wind characteristics using wind speed data that were collected at the six meteorological stations in Turkey from 2000–2006. The annual mean wind speeds for the six locations (Erzurum, Elazig, Bingol, Kars, Manisa and Nigde) were 8.7, 8.5, 5.9, 6.9, 7.4 and 8.0 m/s, respectively, at 10 m height. The annual energy output and capacity factors for the four different turbines were calculated and analyzed in this paper. Ozgener [41] used statistical data of wind speed measurements from the Muradiye Campus at Celal Bayar University to determine the wind energy potential. The mean wind speed was insufficient to provide economical electricity production from the wind energy at this location.

The Osmaniye region has been identified as one of the regions of the country with that is suitable for wind energy systems [6]. Recently, there have been investments in wind power plants, which are located in the mountainous regions nearest to Osmaniye. A case study was conducted to calculate the potential for electricity production from wind energy in the Osmaniye region. This investigation focuses on both the wind energy potential and the investment possibilities for wind energy projects in the Osmaniye Province.

The use of wind energy to produce electricity and the possibility of electrical energy production from wind energy in Osmaniye was studied. The wind data consist of wind speed, direction and flow time at an altitude of 10 m and were obtained from the Turkish State Meteorological Service for a 44-month time frame and statistically analyzed. The paper is organized in the following manner: after this introductory section, the theoretical calculations and an analysis of the wind data in Osmaniye are discussed in Section 2. The results and discussion are provided in Section 3. Finally, the conclusion of the current research is presented in Section 4.

2. Theory and analysis

Knowledge about wind speed distribution is a very important factor for evaluating the wind potential of windy areas. In

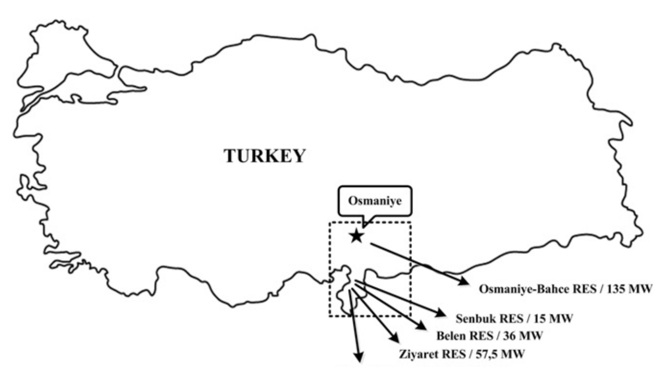

Fig. 2. Location of Osmaniye, Turkey.

addition to the speed distribution, meteorological data and topographical information are equally important [8]. A time series of wind speed data is arranged in the frequency distribution format because it is more appropriate for statistical analysis [28]. For the wind energy analysis, only a few key parameters are needed to explain the behavior of a wide range of wind speed data. The simplest and most practical method for the procedure is to use a distribution function. There are several density functions that can be used to describe the wind speed frequency curve and the two most common functions are the Weibull and Rayleigh functions [8,29]. In this section, hourly time-series wind data from Osmaniye has been analzsed in detail using the Weibull and Rayleigh functions.

2.1. Location and regional description

Osmaniye is located in the eastern Mediterranean region and is bordered by Gaziantep to the east, Adana to the west, Hatay to the south and Kahramanmaras to the north. The coordinates in the Northern Hemisphere are 37.05 north latitude and 36.14 east longitude. The altitude of Osmaniye is 120 m and the distance from the sea is 20 km. The location of the Osmaniye Province is displayed in Fig. 2.

2.2. Wind data

The hourly time-series of wind data consists of wind speed, direction and flow time at an altitude of 10 m and was obtained from the Turkish State Meteorological Service (Osmaniye Station) for January 2008 to August 2011.

2.3. Weibull distribution

The monthly mean wind speed values and standard deviations were calculated from Eqs. (1) and (2) using measured data:

$$v_m = \frac{1}{N}\left[\sum_{i=1}^{N} v_i\right] \tag{1}$$

$$\sigma = \left[\frac{1}{N-1}\sum_{i=1}^{N}(v_i - v_m)^2\right]^{1/2} \tag{2}$$

where v is wind speed, v_m is mean wind speed (m/s), N is the number of hours within the time period and σ is the standard deviation (m/s).

It is important to know the number of hours per month or year during which the given wind speeds occurred, i.e., the frequency distribution of the wind speeds. Generally, previously measured wind data are used to estimate the wind power potential of any area. First, hourly wind speeds and wind directions are observed and monitored. These results are used for frequency and probability modeling. The wind speed data, in time-series format, are usually arranged in the frequency distribution format because it is more convenient for statistical analysis. Therefore, the available time-series data were converted into a frequency distribution format. The wind speed probability distributions and the functions that mathematically represent them are the main tools used in the wind-related literature [33]. When the percentage frequency distribution is plotted against wind, the frequency distribution emerges as a curve and the top of this curve is the most frequent wind speed. This frequency distribution is also used to identify the most suitable site for a wind turbine [42].

The wind speed for a given location can be characterized by several probability density functions. Two of the commonly used functions for fitting a measured wind speed probability distribution in a given location over a certain period of time are the Weibull and Rayleigh functions [4,8,9]. The probability density function of the Weibull distribution is given by

$$f_w(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}\exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{3}$$

where $f_w(v)$ is the probability of having a wind speed of v (m/s), k is a dimensionless shape parameter and c is the Weibull scale parameter, in units of speed (m/s). The relationship between the Weibull scale factor, c, Weibull shape factor, k and the average wind speed, vm, is described by the following formula [8,33]:

$$v_m = c\Gamma\left(1+\frac{1}{k}\right) \tag{4}$$

where the gamma function Γ, has the following properties [8,33]:

$$\Gamma(x) = \int_0^\infty \xi^{x-1}\exp(-\xi)d\xi \text{ and } G(1+x) = xG(x)$$

The cumulative probability function of the Weibull distribution, $F_w(v)$, is calculated mathematically [8]:

$$F_w(v) = 1-\exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{5}$$

As observed in Eqs. (3) and (5), the Weibull distribution is a two-parameter distribution.To estimate the time shape, k and scale, c, parameters of the Weibull distribution from the obtained data, the following methods are applied [17,38,42].

Eq. (6) can be written as

$$\ln[-\ln(1-F_w(v))] = k\ln v - k\ln c \tag{6}$$

here, if $x=\ln v$, $y=\ln[-\ln(1-F_w(v))]$, $A=k$ and $B=-k\ln(c)$ are accepted [38], the function becomes a linear equation. Then, $y=Ax+B$ is obtained from Eq. (6). Additionally, the equation $c=\exp(-B/A)$ is calculated from the equation $B=-k\ln(c)$. The least square method is then applied to calculate A and B[38]:

$$A = \frac{\sum_{i=1}^{N}(x_i-\overline{x})(y_i-\overline{y})}{\sum_{i=1}^{N}(x_i-\overline{x})^2}, B = \overline{y} - A\overline{x} \tag{7}$$

here, $\overline{x}$ (average of x values) and $\overline{y}$ (average of y values) are calculated in Eq. (8):

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{N} f_i x_i, \ \overline{y} = \frac{1}{n}\sum_{i=1}^{N} f_i y_i \tag{8}$$

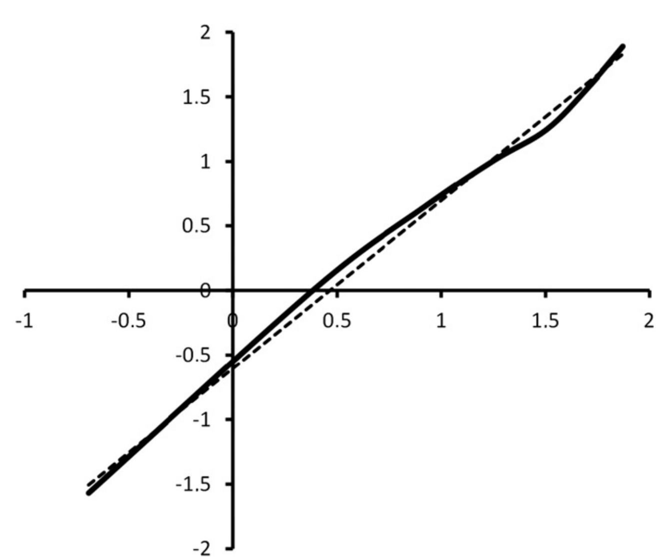

Fig. 3. Linear regression result of the wind data.

Plotting $\ln \nu$ against $\ln[-\ln(1-F_w(\nu))]$ should yield a straight line. The gradient of the line is k and the intercept with the y–axis is $-k\ln(c)$. An example graph for the month of March 2011 is displayed in Fig. 3. The k and c parameters in Eq. (5) of the Weibull distribution can be easily estimated using the wind speed data from the Osmaniye Province as 1.30 and 1.59, respectively.

2.4. Rayleigh distribution

Another distribution function that is used to determine wind speed potential is the Rayleigh distribution. The Rayleigh distribution is a special case of the Weibull model, which typically represents the wind speed frequency distributions. In the Rayleigh distribution, the shape factor, k, is assumed to have a value of 2 [33]. Therefore, the probability density and cumulative distribution functions of the Rayleigh model are given by Eqs. (9) and (10), respectively:

$$f_R(\nu) = \frac{\pi}{2}\frac{\nu}{\nu_m^2}\exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{\nu}{\nu_m^2}\right)^k\right] \tag{9}$$

$$F_R(\nu) = 1-\exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{\nu}{\nu_m}\right)^2\right] \tag{10}$$

where $f_R(\nu)$ is the Rayleigh probability density function and $F_R(\nu)$ is the Rayleigh cumulative distribution function.

2.5. Calculations of wind power

It is well known that the power of the wind, $P(\nu)$, that flows at speed ν through a blade sweep area, A, increases as the cube of its velocity and is described as follows [4,11,33,36,43]:

$$P(\nu) = \frac{1}{2}\rho A(\nu^3)_m \tag{11}$$

where ρ is the standard air density ($\rho = 1.225\ \text{kg/m}^3$ dry air at 1 atm and 15 °C). Akpinar [31] described monthly or annual wind power density per unit area of a region based on the Weibull probability density function, P_W, as given below [4,31,40,44];

$$P_W = \frac{1}{2}\rho c^3\left(1+\frac{3}{k}\right) \tag{12}$$

The power density for the Rayleigh density function, P_R, is calculated using Eq. (13) [4,36];

$$P_R = \frac{3}{\pi}\rho A\nu_m^3 \tag{13}$$

3. Results and discussion

Hourly wind data taken from Turkish State Meteorological Service from January 2008 to August 2011 were used to evaluate the wind energy potential of the Osmaniye Province. A cup anemometer was used to continuously measure wind speed at a height of 10 m above ground level at the Osmaniye Meteorological Station. The annual monthly mean wind speed variations in Osmaniye are illustrated in Fig. 4. It is clear that the minimum wind speed minimum value occurs in November 2010 and that the maximum value occurs in March 2009, with overall values ranging from 1.12 to 2.78 m/s. The annual mean value of the wind speed is calculated for 2008, 2009 and 2010 as 2.21 m/s, 2.23 m/s and 2.20 m/s, respectively. The seasonal mean value of wind speed is calculated for 2011 (from January to August) as 2.28 m/s.

The monthly mean wind speed values and standard deviations are calculated from Eqs. (1) and (2) using measured data, and the time shape, k and scale, c, parameters of the Weibull function are calculated using Eqs. (4) and (5). All of the calculated monthly parameters are lisetd by year in Table 1. The highest wind speed values occur in the months of June 2008 and March 2009 (2.75 and 2.78 m/s, respectively). However, November 2010 and October 2009 have minimum wind speed values of 1.13 and 1.56 m/s, respectively. The Weibull parameters listed in Table 1 indicate that the scale factor, c, varies between 0.66 and 2.31 m/s, while the shape factor, k, ranges from 0.69 to 1.30.

Because the frequency distribution format is more appropriate for statistical analysis, the time series of wind speed data is organized in a frequency distribution format. An example of such data is presented in Table 2 for August 2011. The fourth column of Table 2 lists the frequency with which the wind speed falls within various ranges (bins). The probability density distributions that are calculated from the actual Weibull and Rayleigh functions are presented in the fifth, sixth and seventh columns of Table 2, respectively.

The actual probability density function and cumulative probability distributions that are derived from the measured hourly time series from Osmaniye during the 44-month period are depicted in Fig. 5.

The wind speed frequency distributions were estimated using the Weibull and Rayleigh probability functions and the estimates were compared to the measured probability distribution function. Looking at the graphical results only (Fig. 6), the Weibull distribution fits the actual distribution data closer than the Rayleigh distribution. The shape, k and scale, c, values of the

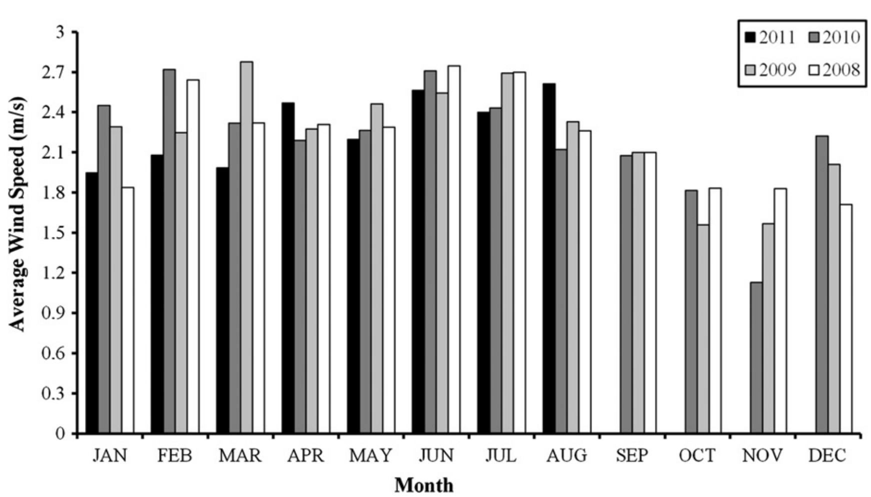

Fig. 4. Monthly wind speed variation in the Osmaniye Province.

Table 1
Distributional parameters on a monthly basis, calculated using wind speed data from the Osmaniye Province.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
v_m (m/s)												
2008	1.84	2.64	2.32	2.31	2.29	2.75	2.70	2.26	2.10	1.83	1.83	1.71
2009	2.29	2.25	2.78	2.27	2.46	2.54	2.69	2.33	2.10	1.56	1.57	2.01
2010	2.45	2.72	2.32	2.19	2.26	2.71	2.43	2.12	2.07	1.81	1.13	2.22
2011	1.95	2.08	1.98	2.47	2.20	2.56	2.40	2.61	–	–	–	–
σ (m/s)												
2008	1.43	2.09	1.67	1.76	1.61	2.04	2.03	1.84	1.56	1.38	1.28	1.93
2009	2.14	1.72	2.15	1.71	1.89	1.84	1.94	1.68	1.54	1.22	1.04	1.67
2010	2.51	2.24	1.69	1.59	1.79	1.95	1.78	1.60	1.64	1.23	0.89	2.24
2011	1.65	1.41	1.17	1.96	1.79	2.09	1.93	2.00	–	–	–	–
c (m/s)												
2008	1.29	2.04	1.77	1.73	1.70	2.15	2.04	1.64	1.53	1.26	1.32	0.96
2009	1.56	1.67	2.31	1.71	1.94	1.93	2.10	1.74	1.56	1.05	1.09	1.40
2010	1.65	2.08	1.86	1.72	1.64	2.08	1.80	1.47	1.42	1.31	0.66	1.38
2011	1.40	1.62	1.59	1.93	1.56	1.88	1.74	1.93	–	–	–	–
k												
2008	0.93	1.02	1.10	1.00	1.13	1.01	1.02	0.79	1.07	0.89	1.06	0.69
2009	0.87	1.02	1.07	1.08	1.01	1.10	1.01	1.07	1.08	0.92	1.02	0.90
2010	0.82	1.00	1.06	1.05	1.00	1.03	1.02	1.01	0.97	1.11	0.91	0.73
2011	0.89	1.14	1.30	1.02	0.97	0.99	0.90	1.05	–	–	–	–

Table 2
Arrangement of the measured hourly time-series data, in frequency distribution format, for August 2011.

i	v_i	v_{mi}	f_i	$f(v_i)$	$f_w(v_i)$	$f_R(v_i)$
1	0–1	0.5	203	0.285	0.400	0.140
2	1–2	1.5	160	0.224	0.250	0.111
3	2–3	2.5	82	0.115	0.149	0.058
4	3–4	3.5	61	0.086	0.086	0.043
5	4–5	4.5	90	0.126	0.050	0.063
6	5–6	5.5	76	0.107	0.028	0.053
7	6–7	6.5	37	0.052	0.016	0.026
8	7–8	7.5	3	0.004	0.009	0.002
9	8–9	8.5	1	0.001	0.005	0.001
10	9–10	9.5	–	0.000	0.003	0.000
11	10–11	10.5	–	0.000	0.002	0.000
12	11–12	11.5	–	0.000	0.001	0.000
13	12–13	12.5	–	0.000	0.000	0.000
14	13–14	13.5	–	0.000	0.000	0.000
15	14–15	14.5	–	0.000	0.000	0.000
16	15–16	15.5	–	0.000	0.000	0.000

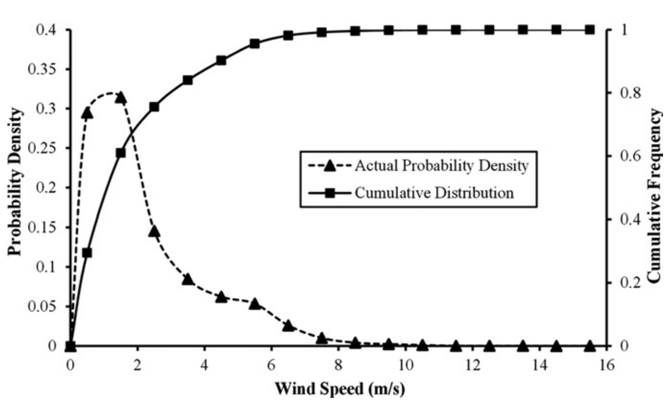

Fig. 5. Wind speed probability density and cumulative probability distributions.

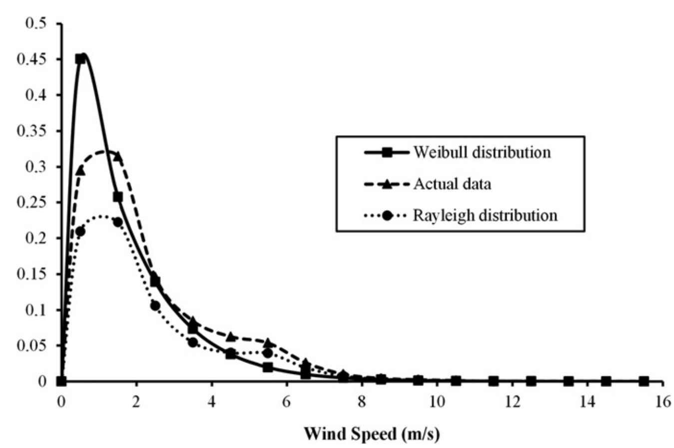

Fig. 6. Wind speed frequency distributions of Osmaniye.

Weibull function were calculated using the method that was mentioned in section II and the k and c parameters of 1.06 and 1.65 m/s, respectively, for the site were analyzed for the 44 month period. The maximum occurrence probability of the site is 0.45 for the Weibull distribution (Fig. 6).

Table 3 illustrates the monthly variation in the power densities by years, based on Weibull, Rayleigh and actual cases. The lowest power densities occur in November of 2009 and 2010, with 6.67 and 3.07 W/m^2, respectively (Table 3). Based on actual data, the highest power density values occur in January 2010 and March 2009 (53.47 and 46.83 W/m^2, respectively).

The Osmaniye Province is compared to other locations that have been previously investigated in Table 4, according to mean wind speed and average power density values. Osmaniye has a higher wind power potential than Keban, Muradiye, Bartin and Ordu, while it is similar in potential to Iskenderun, Kutahya and Mugla, based on their power densities. However, Osmaniye has lower wind power potential than most locations in Turkey, such as Kirklareli, Samandag, Amasra, Belen, Maden, Agin, Elazig, Nurdagi, Canakkale, Balikesir, Istanbul, Tekirdag, Izmir, Mersin, Antalya and Sinop.

The wind speed data for a 44-month period from January 2008 to August 2011 is also analyzed by season. Seasonal variations in the wind characteristics in the Osmaniye Province are summarized in Table 5.

Table 3
Monthly variation in mean power densities (W/m^2) for the Osmaniye Province.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual data												
2008	13.62	38.67	22.81	25.32	20.47	37.87	35.45	23.78	16.94	14.71	11.02	25.71
2009	34.36	22.73	46.83	23.19	32.27	29.29	33.21	22.10	17.67	8.87	6.67	20.59
2010	53.47	46.16	24.80	20.88	24.30	34.46	24.78	17.51	17.94	9.96	3.07	37.85
2011	19.32	15.68	11.09	33.35	23.57	34.59	27.58	32.62	–	–	–	–
Weibull												
2008	10.69	28.78	14.53	18.86	12.07	34.90	29.13	49.66	10.42	12.01	6.97	21.57
2009	24.80	15.89	35.03	13.86	26.09	19.13	32.79	15.07	10.65	6.02	4.37	15.81
2010	39.58	33.80	19.06	15.70	16.46	29.71	19.45	11.22	11.67	5.69	1.56	45.95
2011	16.79	9.99	6.67	24.15	15.61	25.66	30.40	21.85	–	–	–	–
Rayleigh												
2008	7.26	21.58	14.60	14.35	13.99	24.25	23.03	13.51	10.80	7.19	7.16	5.86
2009	14.05	13.26	25.03	13.74	17.41	19.26	22.83	14.76	10.81	4.43	4.50	9.49
2010	17.17	23.54	14.55	12.23	13.56	23.28	16.78	11.15	10.44	6.99	1.67	12.83
2011	8.62	10.50	9.14	17.56	12.40	19.73	16.12	20.88	–	–	–	–

Table 4
Comparison of the Osmaniye Province with other locations in Turkey.

Reference	Location	Latitude	Longitude	Altitude (m)	Wind speed (m/s)	Power density (W/m^2)
	Osmaniye	37° 23′	36° 21′	10.0	2.23	24.59
[8]	Kirklareli	41° 73′	27° 23′	10.0	4.68	142.75
[32]	Samandag	36° 07′	35° 56′	10.0	5.27	143.00
	Amasra	41° 75′	32° 38′		5.20	232.00
[33]	Iskenderun	36° 35′	36° 10′	10.0	2.39	30.20
[34]	Belen-Hatay	36° 29′	36° 11′	10.0	7.00	378.00
[36]	Maden	39° 25′	39° 30′		5.66	246.27
	Agin	35° 56′	38° 42′	10.0	3.86	98.90
	Elazig	38° 60′	39° 28′		3.14	41.37
	Keban	38° 47′	38° 44′		2.27	15.83
[37].	Kutahya	39° 42′	29° 98′	10.0	4.46	36.62
[38]	Nurdagi	37° 18′	36° 72′	10.0	7.30	222.00
[41]	Muradiye	38° 39′	27° 20′	30.0	3.21	19.78
[28]	Canakkale	26° 24′	40° 08′	30.0	7.02	179.00
	Balıkesir	27° 53′	39° 39′		9.95	647.5
	Istanbul	29° 00′	41° 00′		4.83	42.18
	Tekirdag	27° 31′	40° 59′		5.58	74.20
	İzmir	27° 08′	38° 25′		5.52	74.02
	Mugla	28° 22′	37° 15′		4.39	28.11
	Antakya	36° 10′	36° 14′		2.90	85.77
	Mersin	34° 36′	36° 51′		4.74	40.64
	Antalya	30° 45′	36° 52′		4.91	41.29
	Sinop	35° 11′	42° 01′		5.77	75.06
	Bartin	32° 20′	41° 38′		3.86	17.70
	Ordu	37° 53′	41° 00′		3.93	18.49

Table 5
Seasonal variation in wind characteristics for the Osmaniye Province.

	Spring	Summer	Autumn	Winter
Parameters				
v_m (m/s)	2.32	2.51	1.78	2.18
σ (m/s)	1.77	1.91	1.36	1.97
k	1.08	1.11	0.98	0.96
c (m/s)	1.80	1.82	1.23	1.57
Power densities				
Actual data	26.34	29.36	11.87	29.98
Weibull	16.50	15.44	7.42	16.83
Rayleigh	14.61	18.44	6.57	12.24

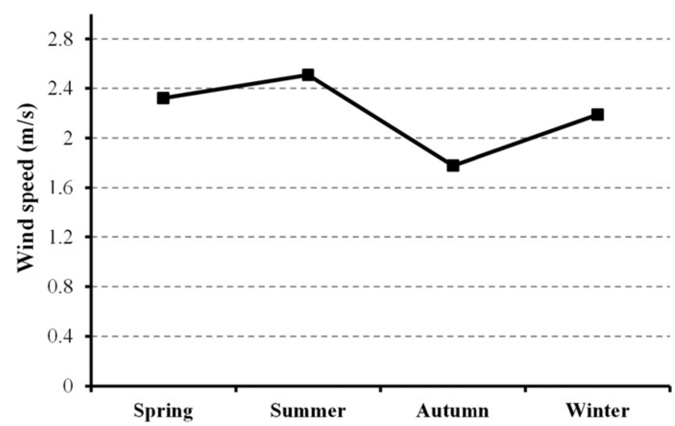

Fig. 7. Seasonal wind speed variation for the Osmaniye Province.

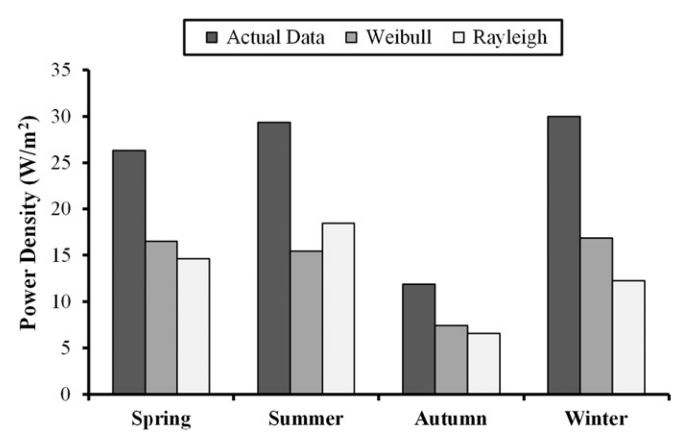

Fig. 8. Seasonal variation in mean power densities for the Osmaniye Province.

The wind speed is highest in the summer, with a value of 2.51 m/s and it is lowest in the autumn, with a value of 1.78 m/s (Table 5). Fig. 7 indicates the seasonal variation in wind speeds for the Osmaniye Province. The Weibull shape parameter, k, is between 0.96 and 1.11, while the scale parameter, c, is between 1.23 and 1.82 m/s in the seasonal analysis. The values of power densities that depend on actual data from summer and winter are 29.36 and 29.98 W/m^2, respectively, which is higher than for

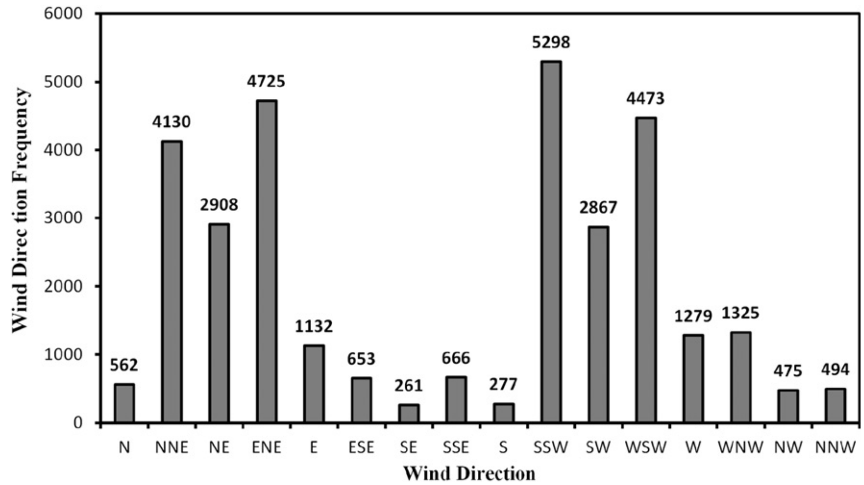

Fig. 9. Wind direction frequency versus wind directions.

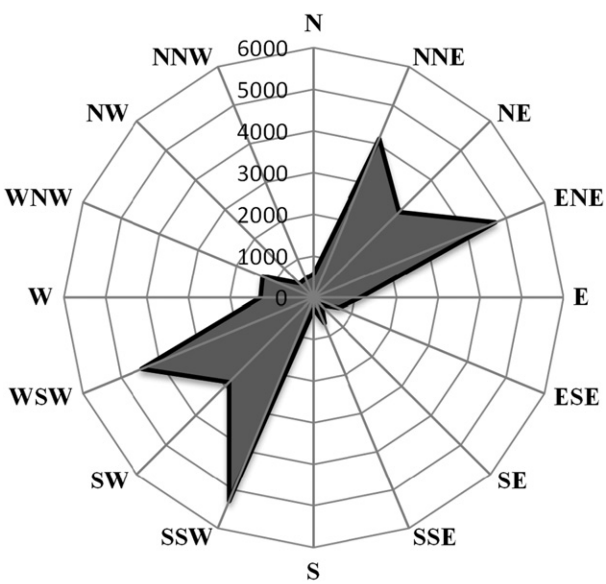

Fig. 10. Wind direction frequency distribution radar chart.

other seasons. Generally, better power density estimates are provided by the Weibull function for several seasons than the Rayleigh model. Fig. 8 displays the seasonal variation in the power densities, based on the Weibull and Rayleigh functions, as well as actual data for the Osmaniye Province.

To determine the optimal position for wind turbines in a wind park area, the wind direction is the most significant parameter. The relationship between the wind direction frequency and wind directions is illustrated in Fig. 9. This figure indicates that there are two dominant regions with prevailing wind directions at Osmaniye. Although the maximum frequency of occurrence is ENE (east-northeast) for the first region, which includes NNE, NE and ENE winds, it is SSW (south-southwest) for the second region, which includes SSW, SW and WSW winds. The wind rarely blows from the south (S) and the southeast (SE) directions.

Fig. 10 displays the wind direction frequencies at Osmaniye based on radar demonstrations. However, the power that is generated is proportional to the cube of wind speed. Therefore, the average wind power density in each direction is a useful way to evaluate the available wind resource under consideration at this site. Fig. 11 displays the calculated values of average power density, with respect to the wind directions, in the Osmaniye Province.

As clearly observed in Fig. 11, the highest power density for the 44-month time period is in the south-southwest direction (SSW) (52.7 W/m^2), while the lowest power density is in the north (N) (4.1 W/m^2).

4. Conclusion

An hourly time-series of measured wind speed data for the Osmaniye Province was graphically analyzed for a period from January 2008 to August 2011. The power density distributions were derived and the distributional parameters were determined. The wind energy potential of the location was analyzed using the Weibull and Rayleigh models. The most important results of the study are summarized below.

The mean wind speed for the Osmaniye Province, at a height of 10 m above ground level, is 2.23 m/s over a 44-month time period. The observed data indicate that the maximum recorded value of wind speed at this location was 2.78 m/s (March 2009), while the minimum value is 1.13 m/s (November 2010).

A seasonal analysis indicates that the wind speed is highest in summer and lowest in autumn. Additionally, the power densities that depend on actual data for summer and winter are higher than other seasons.

The average wind energy potential over the 44 months was 24.587 W/m^2 for the Osmaniye Province. The maximum power occurred on January 2010 (53.47 W/m^2) and the minimum power occurred on November 2010 (3.07 W/m^2).

According to the wind direction frequency distribution radar chart, the wind direction is maximum in the SSW and ENE directions. If fixed wind turbines are placed in this territory, the head of the wind turbine should be parallel to these wind directions to provide greater benefits by capturing the wind directly.

These results demonstrate that the ability to generate power from wind energy is low in the Osmaniye Province and cannot provide energy demands directly. The region near the city of Osmaniye may be adequate for non-connected electrical and mechanical applications, such as battery charging and water pumping. The results should be reevaluated over the long term based on advances in technology and reductions in the cost of turbines.

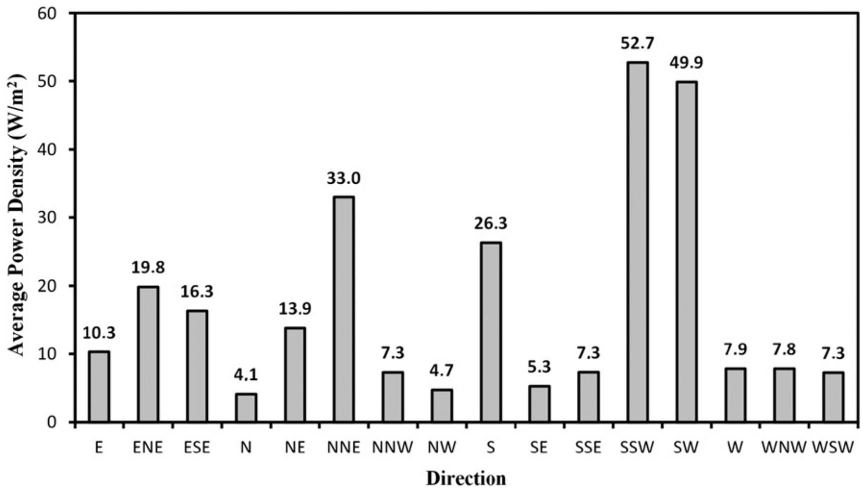

Fig. 11. Average power density versus wind direction.

References

[1] Guler Onder. Wind energy status in electrical energy production of Turkey. Renewable and Sustainable Energy Reviews 2009;13:473–8.

[2] Kaygusuz Kamil. Wind energy status in renewable electrical energy production in Turkey. Renewable and Sustainable Energy Reviews 2010;14:2104–12.

[3] Erdogdu Erkan. On the wind energy in Turkey. Renewable and Sustainable Energy Reviews 2009;13:1361–71.

[4] Oguz Arslan. Technoeconomic analysis of electricity generation from wind energy in Kutahya. Turkey. Energy 2010;35:120–31.

[5] Onat Nevzat, Ersoz Sedat. Analysis of wind climate and wind energy potential of regions in Turkey. Energy 2011;36:148–56.

[6] Cumali Ilkilic. Wind energy and assessment of wind energy potential in Turkey. Renewable and Sustainable Energy Reviews 2012;16:1165–73.

[7] Zorlu Energy Group, 〈http://www.zoren.com.tr/EN/ABOUT/default.asp〉; 2011.

[8] Gokcek Murat, Bayulken Ahmet. and Bekdemir Sukru. Investigation of wind characteristics and wind energy potential in Kirklareli. Turkey. Renewable Energy 2007;32:1739–52.

[9] Youm I, Sarr J, Sall M, Ndiaye A, Kane MM. Analysis of wind data and wind energy potential along the northern coast of Senegal. Renewable and Sustainable Energy Reviews 2005;8:95–108.

[10] Keyhani A, Ghasemi-Varnamkhasti M, Khanali M, Abbaszadeh R. An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran. Energy 2010;35:188–201.

[11] Tchinda Rene, Kaptoum Ernest. Wind energy in Adamaoua and North Cameroon provinces. Energy Conversion and Management 2003;44:845–57.

[12] Lima Laerta de Araujo, Filho Celso Rosendo Bezerra. Wind energy assessment and wind farm simulation in Triunfo-Pernambuco. Brazil. Renewable Energy 2010;35:2705–13.

[13] Albuhairi Mahyoub H. Assessment and analysis of wind power density in Taiz- republic of Yemen. Assiut University Bulletin for Environmental Researches 2006;9:2.

[14] Mostafaeipour A, Sedaghat A, Dehghan-Niri AA, Kalantar V. Wind energy feasibility study for city of Shahrbabak in Iran. Renewable and Sustainable Energy Reviews 2011;15:2545–56.

[15] Mirhosseini M, Sharifi F, Sedaghat A. Assessing the wind energy potential locations in province of Semnan in Iran. Renewable and Sustainable Energy Reviews 2011;15:449–59.

[16] Dahmouni AW, Salah Ben M, Askri F, Kerkeni C, Nasrallah Ben S. Assessment of wind energy potential and optimal electricity generation in Borj-Cedria, Tunisia. Renewable and Sustainable Energy Reviews 2011;15:815–20.

[17] Ioannis Fyrippis, Axaopoulos Petros J, Gregoris Panayiotou. Wind energy potential assessment in Naxos Island. Greece. Applied Energy 2010;87:577–86.

[18] Meishen Li, Xianguo Li. Investigation of wind characteristics and assessment of wind energy potential for Waterloo region, Canada. Energy Conversion and Management 2005;46:3014–33.

[19] Kitaneh Rushdi, Alsamamra Husain, Aljunaidi Abeer. Modeling of wind energy in some areas of Palestine. Energy Conversion and Management 2012;62:64–9.

[20] Mohammadi Kasra, Mostafaeipour Ali. Using different methods for comprehensive study of wind turbine utilization in Zarrineh, Iran. Energy Conversion and Management 2013;65:463–70.

[21] Mostafaeipour Ali, Sedaghat Ahmad, Ghalishooyan Morteza, Dinpashoh Yagob, Mirhosseini Mojtaba, Sefid Mohammad, Rezaei Maryam Pour. Sefid Mohammadet al. . Evaluation of wind energy potential as a power generation source for electricity production in Binalood, Iran. Renewable Energy 2013;52:222–9.

[22] Alamdari P, Nematollahi O, Mirhosseini M. Assessment of wind energy in Iran: a review. Renewable and Sustainable Energy Reviews 2012;16:836–60.

[23] Lashin Aref, Shata Ahmed. An analysis of wind power potential in Port Said, Egypt. Renewable and Sustainable Energy Reviews 2012;16:6660–7.

[24] Aman MM, Jasmon GB, Ghufran A, Bakar AHA, Mokhlis H. Investigating possible wind energy potential to meet the power shortage in Karachi. Renewable and Sustainable Energy Reviews 2013;18:528–42.

[25] Durisic Zeljko, Mikulovic Jovan. Assessment of the wind energy resource in the South Banat region, Serbia. Renewable and Sustainable Energy Reviews 2012;16:3014–23.

[26] Himri Y, Rehman S, Agus Setiawan A, Himri S. Wind energy for rural areas of Algeria. Renewable and Sustainable Energy Reviews 2012;16:2381–5.

[27] Mpholo Moeketsi, Mathaba Tebello, Letuma Mosuoe. Wind profile assessment at Masitise and Sani in Lesotho for potential off-grid electricity generation. Energy Conversion and Management 2012;53:118–27.

[28] Ucar Aynur, Balo Figen. Assessment of wind power potential for turbine installation in coastal areas of Turkey. Renewable and Sustainable Energy Reviews 2010;14:1901–12.

[29] Ucar Aynur, Balo Figen. Investigation of wind characteristics and assessment of wind-generation potentiality in Uludag-Bursa, Turkey. Applied Energy 2009;86:333–9.

[30] Eskin N, Artar H, Tolun S. Wind energy potential of Gokceada Island in Turkey. Renewable and Sustainable Energy Reviews 2008;12:839–51.

[31] İlkilic Cumali, Türkbay İsmail. Determination and utilization of wind energy potential for Turkey. Renewable and Sustainable Energy Reviews 2010;14:2202–7.

[32] Onat Nevzat, Ersoz Sedat. Analysis of wind climate and wind energy potential of regions in Turkey. Energy 2011;36:148–56.

[33] Celik Ali Naci. A Statistical analysis of wind power density based on the Weilbull and Rayleigh models at the southern region of Turkey. Renewable Energy 2003;29:593–604.

[34] Sahin Besir, Bilgili Mehmet. Wind characteristics and energy potential in Belen-Hatay, Turkey. International Journal of Green Energy 2009;6:157–72.

[35] Ozerdem B, Turkeli HM. Wind energy potential estimation and micrositting on Izmir Institute of Technology Campus, Turkey. Renewable Energy 2005;30:1623–33.

[36] Akpinar E, Kavak A. Statistical ınvestigation of wind energy potential. Energy Sources, Part A 2006;28:807–20.

[37] Kose Ramazan. An evaluation of wind energy potential as a power generation source in Kütayha, Turkey. Energy conversation and Management 2004;45: 1631–41.

[38] Karsli VM, Gecit C. An investigation on wind power potential of Nurdağı-Gaziantep, Turkey. Renewable Energy 2003;28:823–30.

[39] Celik Ali N. Review of Turkey's current energy status: a case study for wind energy potential of Canakkale province. Renewable and Sustainable Energy Reviews 2011;15:2743–9.

[40] Ucar Aynur, Balo Figen. Evaluation of wind energy potential and electricity generation at six locations in Turkey. Applied Energy 2009;86:1864–72.

[41] Ozgener Leyla. Investigation of wind energy potential of Muradiye in Manisa, Turkey. Renewable and Sustainable Energy Reviews 2010;14:3232–6.

[42] Shata, Ahmed. Theoretical investigation and mathematical modeling of a wind energy system case study for Mediterranean and Red Sea. M.Sc. Thesis. Technical University of Berlin; 2008.

[43] Kavak Akpinar E, Akpinar S. An assessment of wind turbine characteristics and wind energy characteristics for electricity production. Energy Sources, Part A 2006;28:941–53.

[44] Akdag Seyit A, Dinler Ali. A new method to estimate Weibull parameters for wind energy applications. Energy Conversion and Management 2009;50: 1761–6.